the basis of health and safety to the public and site workers.

Questions regarding the applicability of individual fire safety directives to a particular confinement ventilation design as well as requests for interpretation of the provisions of industry standards to such designs should be directed to the cognizant USNRC or DOE fire protection authority having jurisdiction.

10.4 ENCLOSURE FIRE MODELING IN FIRE HAZARDS ANALYSIS

DOE has developed a useful framework for analyzing the fire hazard in a facility. This framework considers all of the aspects of fire and its impact on people, continuity of operation, the environment, and the public. The occurrence and spread of fire is a complex process that cuts across many design and operational disciplines which makes its control over the lifetime of a facility problematical in some respects.

The FHA for a confinement ventilation system should contain a conservative assessment of the following issues and their relation to fire.

- Description of construction

- Description of critical process equipment

- Description of fire hazards, including a design basis fire and its effects on the confinement ventilation system, and the limits of the ability of the confinement ventilation system to withstand fires more severe than the design basis fire

- Protection of essential safety class systems

- Life safety considerations

- Critical process equipment

- Identification of high-value property

- Identification of the damage potential: Maximum Credible Fire Loss (MCFL) and Maximum Possible Fire Loss (MPFL)

- Analysis of Fire Department/Brigade response and its adequacy

- Recovery potential

- Potential for a toxic, biological, and/or radiation incident due to a fire

- Analysis of Emergency Planning and its ability to mitigate a fire in a confinement ventilation system

- Security and Safeguards considerations related to fire protection

- Impacts of natural hazards (earthquake, flood, wind) on fire safety

- Exposure fire potential, particularly concerning the potential for breaching of the confinement ventilation system due to a fire external to the system

The FHA considers everything to do with the design and operation of the facility. The essential tools for analysis are predictive models that can be applied to define the ranges of hazards from design basis events (DBEs). An FHA can be applied during the design phase of new facilities and/or in conjunction with changes or modifications of existing operations. Fire models for FHAs range from simple algorithms that predict thermodynamic changes in enclosures to complex programs that can account for heat, mass transfer, and smoke production in multiple enclosures. Many mathematical models have been installed in computer codes and are available on the Internet bulletin boards of various government agencies. These codes can predict development and spread of fire and smoke conditions through multiple rooms, and can account for changes in the structure and composition of enclosures. Application of these models requires considerable understanding of their use and limitations, statements of which are usually included in the instructional text that is published with the code. Information about these codes is found in Section 10, Chapters 6 through 14 of the 17th edition of the NFPA Handbook.[25] Reduction of complex models to simple terms supported by empirical data can often be useful in making predictions of uncomplicated systems.

As shown, the temperature of the hot upper layer formed by fire in the LLNL fire test cell is plotted and compared to a temperature correlation based on the mass flow rate of air, the heat release rate of the fire, and the thermal properties of the test cell surfaces. While this model does not have an

algorithm for smoke production, many references are available that provide ratios and rates of combustion product development as a function of heat release rate.[27] A practical example of the use of predictive modeling is a study done for the Transuranium Processing Plant at Oak Ridge National Laboratory (ORNL).[28] This analysis was done to determine whether the final HEPA filters in the facilities off-gas ventilation system were at risk from fire in the hot cells. Due to the nature of the activities performed in the hot cell facilities, there is a justified potential for accumulation of flammable materials over longer-than-desirable periods of time. These facilities are well engineered and at times contain ignition sources. In addition, they are often protected by heat detector-activated water deluge sprinklers, and the shutdown procedures generally involve isolation of the cell and either termination or reduction of its air supply. Since the enclosure construction is necessarily massive for shielding purposes, heat losses for fires in the cell are very large. These factors combine to make hot cells and assorted caves inherently fire-resistant. Nonetheless, this analysis was prompted by the concerns of an independent consultant about the resident fire load in some cubical of this facility. The modeling predictions showed that the maximum credible fire would become oxygen-depleted before hazardous conditions could escape the cubical. In addition, the predicted equilibrium temperatures from these fires would be cooled to acceptably low temperatures by dilution and convective heat transfer along the ventilation circuit to the filter plenum.

Tests were later done using the LLNL fire test cell modified to simulate the cubical at ORNL. The tests confirmed the conditions predicted by the modeling study. The only difference in results between the physical tests and the mathematical modeling effort was that the overall cost of the tests program was ten times higher.[29]

10.5   FIRE PHENOMENA

This section is divided into segments discussing some of the phenomena associated with fires occurring outside the confinement ventilation systems, as well as within these systems. For each of these types of fires, the subject matter is further divided according to the matrix show in **TABLE 10.1**.

Fire is a complex phenomenon that involves the initiation of an event and subsequent actions that can mitigate or exacerbate the event's effects. The matrix in TABLE 10.1 first covers the initiation and generation of harmful products from a fire. Then the means by which these harmful effects are transported throughout the confinement ventilation system are discussed. Finally, the impacts of these harmful effects on the main components of the confinement ventilation system are discussed. The material in this section indicates the fire hazards that must be mitigated. The techniques for mitigation are presented in the next section.

TABLE 10.1 – Fire Phenomena Matrix

	Heat	Smoke	Related Effects
Generation	Fire growth	Initial Aerosol makeup	Water vapor, Chemical releases, deflagrations
Transport	Temps in ducts	Change in aerosol with time and temperature	Change with movement through ducts
Effects on Filters	Media failure	Filter Media plugging	Filter Media plugging and failure

10.5.1   FIRES OCCURRING OUTSIDE A CONFINEMENT VENTILATION SYSTEM

Fires occurring outside a confinement ventilation system generate combustion products that are drawn into the confinement ventilation system when it operates as intended. These combustion products will affect the components of the confinement ventilation system.

10.5.1.1   GENERATION OF HEAT, SMOKE, AND RELATED PRODUCTS

Thermal Effects From Fire Initiation and Growth

Issues concerning the events that initiate fires can be solved by examining the known history of things that have caused fires in nuclear facilities in the past and by designing systems to accepted standards. Where unknowns are found to exist, unique hazard and failure modes analyses can be